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Estimation of traffic load effects on Forth Road Bridge using camera measurements

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ABSTRACT: This paper explores the possibility of using a camera and image analysis to extract congested traffic data. A video system was installed on the Forth Road Bridge. The system captured traffic video data at a rate of 1 frame per second for approximately five months. Simple image processing methods, e.g. adaptive thresholding and morphological reconstruction, are used to automatically analyse the images extracted from the videos. The body shapes of the vehicles are accurately extracted. Identified vehicles are framed within rectangles and the rectangle's dimensions are used to approximate the length of the vehicles. The study confirms that the image data can be used efficiently to measure the lengths of the vehicles. The vehicle lengths can be ultimately used for the estimation of site specific characteristic maximum traffic load effects.

KEY WORDS: bridge; camera; image; long-span; vehicle length; WIM.

1 INTRODUCTION

In recent years, the transportation of goods on roads has been constantly increasing [1]. Due to this fact, the effects of traffic on both the utility and safety of existing bridges have grown. Bridge traffic loading is an overlooked field [2-4] in comparison to resistance which has been extensively questioned [5-7].

For long-span bridges, congestion corresponds to the critical loading cases [8-10]. Traffic congestion is defined by a higher percentage of vehicles with small clearances in between occurring on the bridge at once. Traffic data is gathered globally through Weigh-in-Motion (WIM) systems [11]. However, only free-flowing traffic can be surveyed using such systems [12]. In general, WIM systems are ineffective at collecting congested traffic data, e.g. car-truck mixture and inter-vehicle clearances and the weights of vehicles in congested situations. Thereby, the accurate evaluation of traffic loading on long-span bridges becomes an issue.

There has been little attention directed towards bridge traffic loading [13-16], even though the load effects represent a critical factor in bridge reliability assessment. Traffic loading on long-span bridges can be modelled using the microsimulation method [2, 9], which estimates particular characteristics for individual vehicles [17]. OBrien et al. [15] consider vehicles' responses to the traffic conditions to estimate the car-truck mix in congested situations and how it differs from free-flowing conditions. The difference in the calculated load effect was found, for one example, to be about 10%. Nevertheless, traffic data recorded by WIM systems in free-flowing conditions is in general used to model traffic loading on long-span bridges. This is since most WIM technologies do not collect reliable data in congested traffic conditions. Traffic data (e.g. vehicle mix, traffic speed and density) are also necessary in applications such as intelligent transportation systems (ITS) to improve the quality of road transport [18]. In this field, computer vision and image processing methods are used to collect data about traffic. These

methods allow a better vehicle identification [19] and classification in various conditions of traffic [20, 21]. Furthermore, the traffic density can be measured [22] as well as the speed of vehicles [23]. Micu et al. [24] introduce standard image processing techniques as a novel method to gather traffic data in congestion. They confirm that the image data can provide valuable information to assess the bridge traffic loading. While much more traffic data could be extracted from images, the shortcoming of this approach is that it cannot weigh the vehicles. However, a length/weight relationship can be applied to infer estimates of weights from extracted lengths.

This study introduces the idea of using a camera and image processing methodologies to evaluate the traffic loading effects on the Forth Road Bridge (FRB). Five months of traffic data stored in images are analysed by applying standard image processing techniques, e.g. adaptive thresholding and morphological reconstruction. Each image is divided into its three colour intensity components (RGB - red, green, blue) and each of them is individually analysed. The accumulation of all three individual results provide more accurate data concerning the vehicles' body shapes. Each identified vehicle is framed within a rectangle and their lengths are estimated using the dimensions of the rectangles. A statistical correlation between lengths and weights is established to estimate the traffic loading on the bridge.

2 DATABASE

2.1 Forth Road Bridge

Traffic travelling on the Forth Road Bridge is captured and analysed in this work. FRB is a 2.5 km suspension bridge serving the traffic travelling between the north and south of Scotland for more than 53 years. The bridge consists of a two-lane carriageway, cycle and footpaths in each direction. The bridge elevation is approximately 155 m and the clearance between the towers is around 1006 m. After the opening of the Queensferry Crossing Bridge in August 2017, the FRB is

closed to general traffic and forms part of a Public Transport Corridor.

2.2 Equipment for traffic monitoring

A video system was installed on the FRB South Main Tower (Figure 1). This video system includes 1 internet protocol camera (IP camera), 1 network video recorder (NVR) and 1 Power-over-Ethernet (PoE) power supply. One single cable supplies the power and network connection from the PoE support to the camera. The NVR has an embedded 6TB hard drive used for record storage.

The video equipment was set in place in 2017 and captured traffic on the bridge from April to the end of August. The equipment collected video of the traffic on the south side span for both directions at a rate of 1 frame per second.

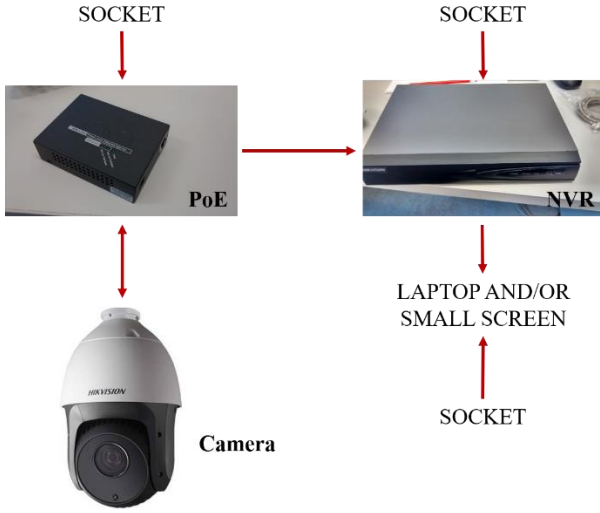


Fig. 1: Equipment used on FRB.

3 IMAGE DATA

An example of a colour image of two vehicles travelling on the northbound lanes of the FRB is illustrated in Fig 2(a). Digital images are data captured by photographic devices and stored in big matrices. The elements of these matrices are called pixels and they represent colour and/or light intensity of the picture elements. A colour image is characterized by a three-dimensional matrix where a colour is represented using three component intensities – RGB (red, green and blue). Fig 2(b) is an example of RGB intensities for the small area of the red car enclosed by the yellow rectangle in Fig 2(a). In contrast, only one intensity is necessary to represent a monochrome image because the data is store in a two-dimensional matrix [25]. On the FRB, the images were in colour and the presence of a vehicle can be detected using the examination of the three numbers for each pixel.



a)

R:158	R:163	R:164	R:166	R:169	R:171	R:172	R:173	R:172	R:171	R:170	R:167
G:151	G:158	G:161	G:165	G:168	G:170	G:171	G:171	G:170	G:169	G:169	G:165
B:160	B:167	B:171	B:177	B:181	B:182	B:184	B:187	B:188	B:188	B:187	B:184
R:137	R:143	R:144	R:148	R:151	R:159	R:161	R:162	R:161	R:160	R:159	R:160
G:128	G:135	G:136	G:143	G:145	G:154	G:156	G:157	G:155	G:154	G:153	G:154
B:133	B:141	B:145	B:154	B:156	B:165	B:168	B:171	B:172	B:173	B:172	B:171
R:125	R:130	R:130	R:132	R:134	R:136	R:137	R:137	R:135	R:134	R:132	R:130
G:98	G:105	G:107	G:112	G:114	G:117	G:118	G:118	G:117	G:116	G:115	G:113
B:101	B:110	B:115	B:122	B:124	B:126	B:129	B:131	B:131	B:132	B:130	B:128
R:119	R:113	R:109	R:104	R:103	R:102	R:100	R:98	R:95	R:92	R:90	R:88
G:62	G:62	G:61	G:59	G:58	G:58	G:56	G:55	G:55	G:54	G:53	G:52
B:67	B:67	B:67	B:68	B:68	B:67	B:65	B:65	B:64	B:63	B:64	B:66
R:144	R:125	R:119	R:115	R:114	R:115	R:114	R:113	R:109	R:106	R:103	R:100
G:62	G:48	G:46	G:46	G:44	G:46	G:46	G:45	G:45	G:45	G:44	G:43
B:63	B:49	B:50	B:52	B:51	B:52	B:52	B:52	B:50	B:48	B:50	B:52
R:171	R:153	R:149	R:145	R:147	R:148	R:150	R:150	R:147	R:144	R:141	R:138
G:66	G:52	G:50	G:51	G:53	G:55	G:58	G:59	G:58	G:58	G:57	G:57
B:63	B:48	B:48	B:50	B:52	B:54	B:57	B:59	B:58	B:58	B:58	B:59
R:196	R:192	R:187	R:185	R:188	R:193	R:195	R:194	R:191	R:188	R:186	R:183
G:67	G:64	G:64	G:64	G:66	G:73	G:75	G:76	G:76	G:76	G:75	G:74
B:60	B:56	B:55	B:57	B:60	B:65	B:68	B:70	B:70	B:71	B:70	B:70
R:216	R:215	R:214	R:211	R:211	R:211	R:210	R:209	R:207	R:205	R:203	R:201
G:63	G:62	G:63	G:62	G:62	G:63	G:63	G:63	G:64	G:64	G:64	G:65
B:51	B:49	B:49	B:47	B:48	B:48	B:48	B:49	B:50	B:51	B:52	B:53

b)

Figure 2. Example of an image: a) colour image;
b) component intensities of the pixels.
R = Red, G = Green, B = Blue.

3.1 Measuring vehicle lengths

This paper proposes measuring the vehicles lengths from the images. This data is essential to assess the bridge traffic loading. Micu et al. [24] adopted common techniques such as thresholding [26] and morphological reconstruction [27], to extract the length of the object in images. In this paper, the previous work is improved upon by applying an adaptive thresholding approach [28]. Northbound traffic on FRB is the area of interest of this study. Therefore, the images are cropped to consider only this area. An example of an image illustrating only the area of interest for the traffic on the bridge is shown in Fig. 3(a). The RGB component intensities are taken out from the original colour image and then individually presented as monochrome images. The red, green and blue intensities are shown in Figures 3(b), (c) and (d), respectively.

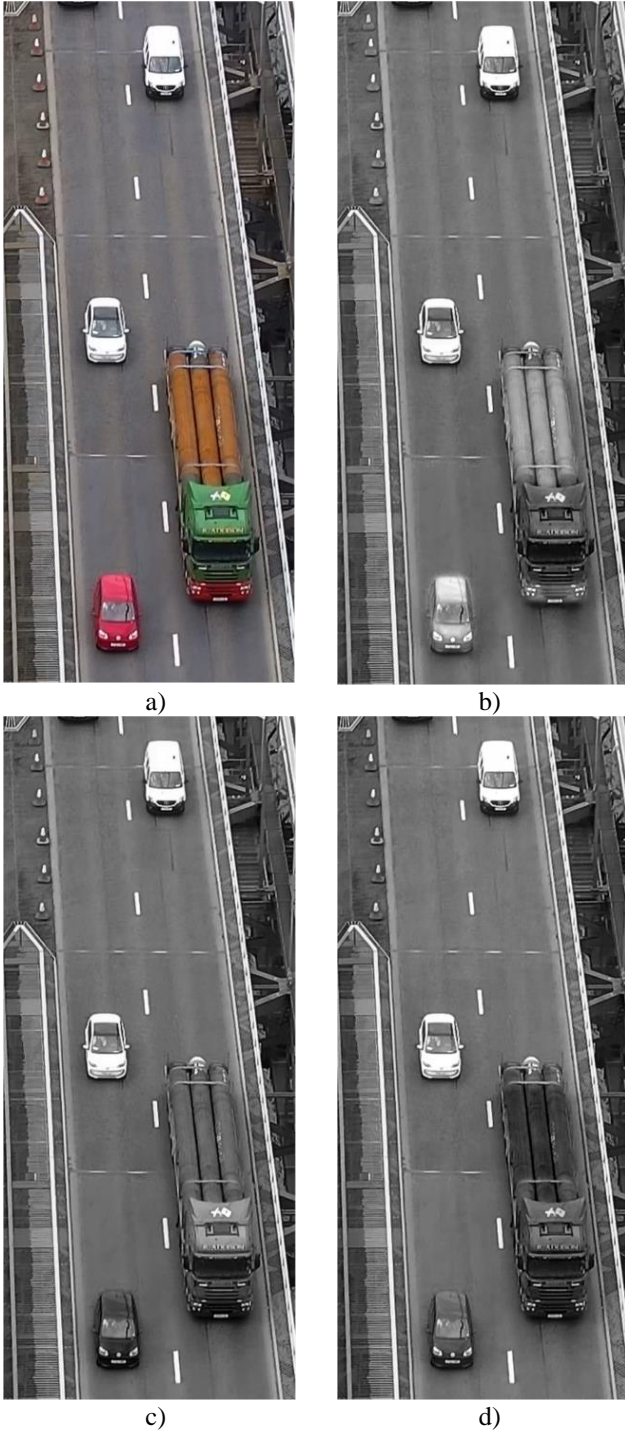


Figure 3. Northbound traffic: a) RGB image – area of interest; b) red intensity; c) green intensity; d) blue intensity.

Every colour intensity is then analysed to extract the vehicle lengths. The results of each colour intensity are concatenated and illustrated as a binary image. Fig. 4(a) presents an example of a binary (black and white) image. It describes a matrix with values for pixel intensity converted to 0's and 1's [29]. Objects with reduced area are removed and vehicle body contours are distinguished as shown in Fig. 4(b). Finally, the vehicles are framed by rectangles. Fig. 4(c) illustrates the results of analysing the image sample in Fig. 3(a). Each rectangle dimensions are then used to extract the length of each vehicle.

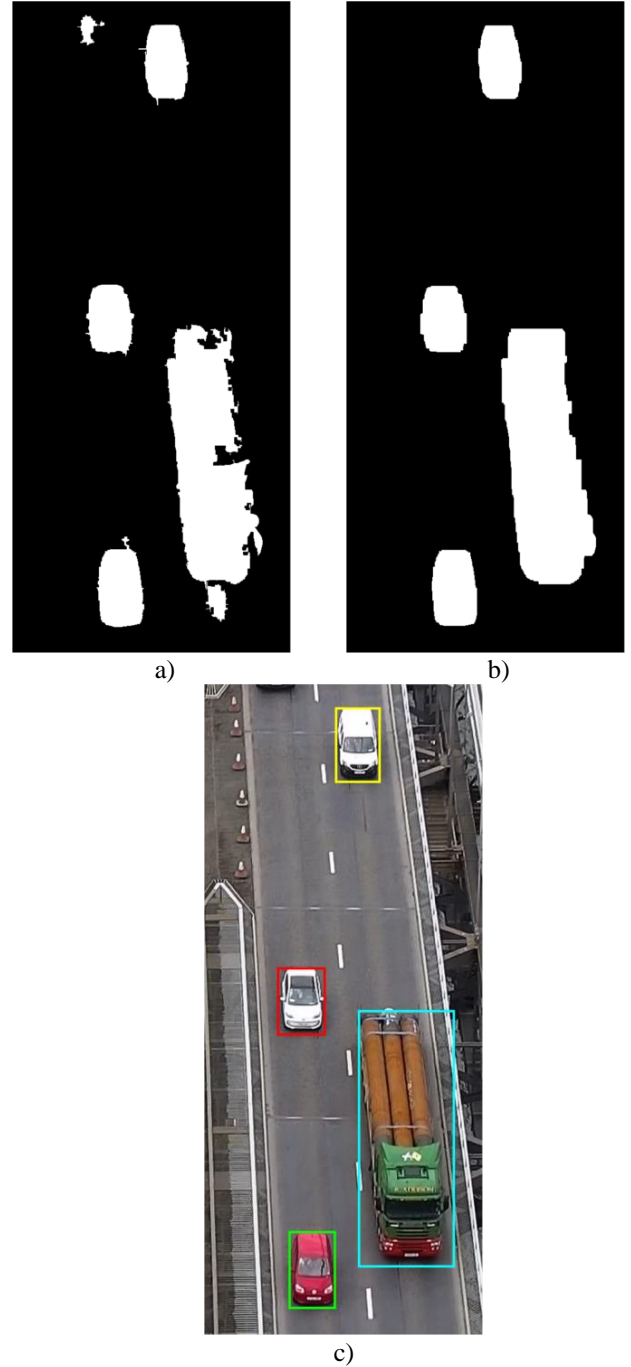


Fig. 5. Image analysis: a) colour intensities results; b) vehicle contours; c) vehicle framed by rectangles.

The stability of the camera is affected by the tower and deck displacements induced by wind. The image data contains errors due to the camera movements. Samples of images with different errors are presented in Fig. 6. Figures 6(a) and (d) illustrates an incomplete detection for one vehicle in each sample. Two samples of proper identification for most vehicles are shown in Fig. 6(b) and (c). In some cases, the length identified in the images does not match the real length of the vehicle, being longer or shorter than the real one. However, the data extracted from images is adequate to infer weights from lengths for statistical purposes. Finally, the bridge loading can be assessed using the inferred weights.

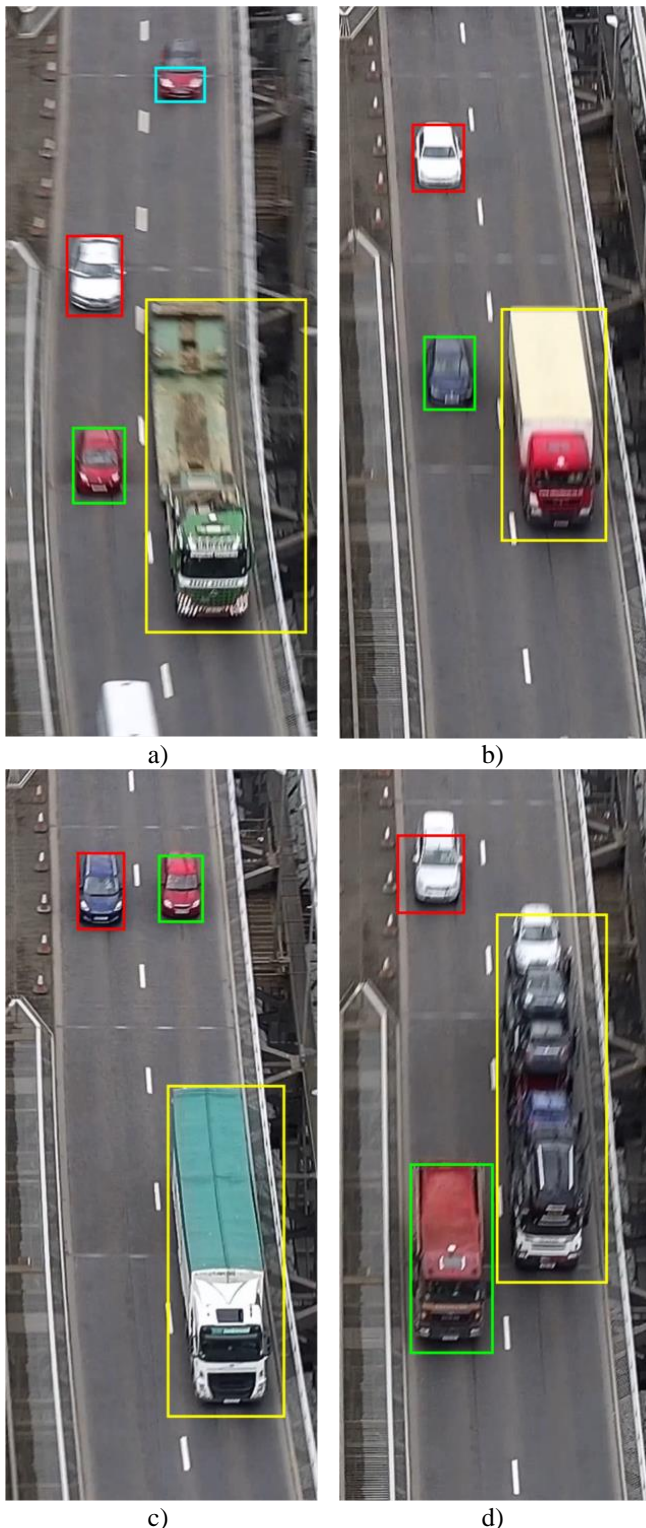


Fig. 6. Examples of vehicle detection: a) sample 1; b) sample 2; c) sample 3; d) sample 4.

SUMMARY AND CONCLUSION

This paper investigates the possibility of using a camera and image analysis methods for monitoring traffic in congested conditions. Traffic on the FRB was recorded as video data for five months by a video system installed on the bridge. Adaptive thresholding as well as morphological reconstruction approaches are applied to analyse the frames extracted from the

video. The identification process is shown to be efficient, and the results are presented as vehicles framed within rectangles. The rectangle dimensions are known, the lengths of the vehicles can be extracted. The outcomes of this work confirm that the camera is a feasible approach to collect data in congested traffic. Further, the purpose is to establish a relationship between lengths in images and weights in WIM data for the accurate assessments of the long-span bridge traffic loading.

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REFERENCES

- [1] European Commission, *EU Energy and Transport in figures*, Luxembourg: Publications Office of the European Union, 2010.
- [2] C. C. Caprani, 'Using microsimulation to estimate highway bridge traffic load', Proc. 5th Intl. Conf. on Bridge Maintenance, Safety and Management, 2010.
- [3] A. Paeglitis, A. Freimanis, 'Comparison of Constant-Span and Influence Line Methods for Long-Span Bridge Load Calculations', *Baltic Journal of Road and Bridge Engineering* 11(1) (2016) 84-91.
- [4] C. Carey, E. J. O'Brien, A. Malekjafarian, M. Lydon, S. Taylor, 'Direct field measurement of the dynamic amplification in a bridge', *Mechanical Systems and Signal Processing* 85 (2017) 601-609.
- [5] M. S. Darmawan, M. G. Stewart, 'Spatial time-dependent reliability analysis of corroding pretensioned prestressed concrete bridge girders', *Structural Safety* 29(1) (2007) 16-31.
- [6] M. G. Stewart, 'Reliability-based assessment of ageing bridges using risk ranking and life cycle cost decision analyses', *Reliability Engineering & System Safety* 74(3) (2001) 263-273.
- [7] M. G. Stewart, D. V. Val, 'Role of load history in reliability-based decision analysis of aging bridges', *Journal of Structural Engineering - ASCE* 125(7) (1999) 776-783.
- [8] G. Sedlacek, G. Merzenich, M. Paschen, A. Bruls, L. Sanpaulesi, P. Croce, J. A. Calgaro, M. Pratt, M. Leendertz Jacob, v. de Boer, A. Vrouwenfelder, G. Hanswille, 'Background document to EN 1991-Part 2-Traffic loads for road bridges-and consequences for the design', JRC—European Commission, 2008.
- [9] C. C. Caprani, E. J. O'Brien, 'The governing form of traffic for highway bridge loading', in: E. Cannon, R. West, P. Fanning (Eds.) Proceedings of 4th Symposium on Bridge and Infrastructure Research in Ireland, National University of Ireland, Galway, 2008, 53-60.
- [10] A. Getachew, 'Traffic load effects on bridges, statistical analysis of collected and Monte Carlo simulated vehicle data', PhD Thesis, Royal Institute of Technology, Stockholm, Sweden, 2003.
- [11] F. Moses, 'Weigh-in-Motion System Using Instrumented Bridges', *Transportation Engineering Journal - ASCE* 105(3) (1979) 233-249.
- [12] E. J. O'Brien, A. Lipari, C. C. Caprani, 'Micro-simulation of single-lane traffic to identify critical loading conditions for long-span bridges', *Engineering Structures* 94 (2015) 137-148.
- [13] P. G. Buckland, J. P. McBryde, F. P. Navin, J. V. Zidek, 'Traffic loading of long span bridges', *Bridge Engineering* 2(665) (1978).
- [14] P. G. Buckland, 'North-American and British Long-Span Bridge Loads', *Journal of Structural Engineering - ASCE* 117(10) (1991) 2972-2987.
- [15] E. J. O'Brien, A. Hayrapetova, C. Walsh, 'The use of micro-simulation for congested traffic load modeling of medium- and long-span bridges', *Structure and Infrastructure Engineering* 8(3) (2012) 269-276.
- [16] A.C.W.M. Vrouwenfelder, P.H. Waarts, 'Traffic loads on bridges', *Structural Engineering International* 3(93) (1993) 169-177.
- [17] M. Treiber, A. Hennecke, D. Helbing, 'Microscopic simulation of congested traffic', in: D. Helbing, H.J. Herrmann, M. Schreckenberg, D.E. Wolf (Eds.), *Traffic and granular flow'99*, Springer Berlin Heidelberg, 2000, 365-376.
- [18] M. Papageorgiou, C. Diakaki, V. Dinopoulou, A. Kotsialos, Y. B. Wang, 'Review of road traffic control strategies', *Proceedings of the IEEE* 91(12) (2003) 2043-2067.

- [19] Y. N. Chen, C. C. Han, G. F. Ho, K. C. Fan, 'Facial/License Plate Detection Using a Two-level Cascade Classifier and a Single Convolutional Feature Map', *International Journal of Advanced Robotic Systems* 12(12) (2015) 183.
- [20] Yu Peng, Jesse S Jin, Suhuai Luo, Min Xu, Yue Cui, 'Vehicle type classification using PCA with self-clustering', *Multimedia and Expo Workshops (ICMEW)*, 2012 IEEE International Conference, 2012, 384-389.
- [21] B. Morris, M. Trivedi, 'Robust classification and tracking of vehicles in traffic video streams', *Intelligent Transportation Systems Conference*, 2006. ITSC'06. IEEE, 2006, 1078-1083.
- [22] B. Coifman, D. Beymer, P. McLauchlan, J. Malik, 'A real-time computer vision system for vehicle tracking and traffic surveillance', *Transportation Research Part C - Emerging Technologies* 6(4) (1998) 271-288.
- [23] P. Reinartz, M. Lachaise, E. Schmeer, T. Krauss, H. Runge, 'Traffic monitoring with serial images from airborne cameras', *ISPRS Journal of Photogrammetry and Remote Sensing* 61(3-4) (2006) 149-158.
- [24] E. A. Micu, E. J. O'Brien, E. Sevillano, 'Application of image processing to the analysis of congested traffic', in: J. Goggins (Ed.) *Proceedings of Civil Engineering Research in Ireland*, Galway, 2016, 317-320.
- [25] R. C. Gonzalez, R. E. Woods, S. L. Eddins, *Digital Image Processing Using MATLAB*, 2nd ed., Gatesmark Publishing, USA, 2009.
- [26] N. Otsu, 'A threshold selection method from gray-level histograms', *IEEE transactions on systems, man, and cybernetics* 9(1) (1979) 62-66.
- [27] L. Vincent, 'Morphological grayscale reconstruction in image analysis: Applications and efficient algorithms', *Transactions on Image Processing - IEEE* 2(2) (1993) 176-201.
- [28] D. Bradley, G. Roth, 'Adaptive thresholding using the integral image', *Journal of graphics tools* 12(2) (2007) 13-21.
- [29] A. McAndrew, *An introduction to digital image processing with Matlab*, Course Technology Press Boston, MA, United States, 2004.